TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 642

INTERFERENCE OF WING AND FUSELAGE FROM TESTS OF EIGHT COMBINATIONS IN THE N.A.C.A. VARIABLE-DENSITY TUNNEL COMBINATIONS WITH TAPERED FILLETS AND STRAIGHT-SIDE JUNCTURES

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SUMMARY

The round fuselage of an unfilleted low-wing combination was modified to incorporate straight-side junctures. The resulting combination, with or without horizontal tail surfaces, had practically the same aerodynamic characteristics as the corresponding round-fuselage tapered-fillet combination.

INTRODUCTION

In references 1 to 5 are reported successive phases of a comprehensive program of investigation of the aerodynamic interference between wing and fuselage in progress in the N.A.C.A. variable-density wind tunnel. The discussion of the program and the basic part of the research comprising test results for 209 wing-fuselage combinations are presented in reference 1. The subsequent papers deal more extensively with the different aspects of the investigation.

The standard fuselage shape employed in the wing-fuselage interference investigation is the round, or airship-form, fuselage. In practical design problems, the airship form provides an aerodynamically favorable, structurally strong fuselage. When employed in a low-wing combination, however, the round fuselage often requires tapered fillets to avoid an interference burble and to maintain the favorable aerodynamic characteristics (references 1 and 2). Such a requirement is disadvantageous because fillets may add to the cost and weight. Tests of combinations with the rectangular fuselage indicated how the round fuselage could be modified to remove the necessity for fillets in the low-wing condition. Fillets serve mainly to fill out the divergent flow passages that are primarily responsible for the interference burble. (See reference 1.) The straight-side junctures formed by the rectangular fuselage when combined with a wing tend to minimize such divergences and their effects (references 1 and 2) although, on the other hand, the presence of the sharp edges of a rectangular shape cannot be considered good aerodynamic practice. Such test results, however, agree with the observation that many low-wing airplanes with flat fuselage sides had apparently little need for fillets.

The present investigation is intended to provide data on the effects of modifying the round fuselage of a low-wing combination to produce flat sides at the junctures while retaining as much as practicable of the smooth curves afforded by the round fuselage. The model employed was patterned after the Lockheed Electra airplane, an example of the use of flat fuselage sides to avoid filleting (reference 6). Its characteristics are compared herein with those of the corresponding round-fuselage combinations, the effects of adding horizontal tail surfaces being included. A future report is planned that will present the results and analysis of the investigation of the interference between wing-fuselage combination and tail from which the foregoing combinations were taken.

MODELS AND TESTS

The round fuselage and the tapered N.A.C.A. 0018-09 airfoil of reference 1 were employed to form the combinations. Only two wing positions were investigated: the low-wing (wing internally tangent to surface of fuselage) and, as a matter of routine, the corresponding high-wing. The tapered fillets were formed of plaster of paris and were of standard form. (See reference 1.) The straight-side juncture modification was made also with plaster of paris added to the original round fuselage (fig. 1) and resulted in the fuselage shape shown in figures 2 and 3. The figures show the modification in fuselage shape sufficiently well to permit reproduction within the accuracy necessary to repeat the test results. Test experience with tapered fillets has shown that such modifications are not very critical as regards dimensions. The juncture regions, formerly smooth plaster surfaces, were provided with the polished lacquer finish now standard for the wing-fuselage interference investigation. (See reference 5.) The horizontal tail surfaces, when added (fig. 3), were set at 0° ($i_s = 0°$) to the wing (which was at zero incidence). The projected area is 27 square inches, and the effective aspect ratio (in the tunnel) is 4.58. Figure 4 shows the details of the tail-surface panel. Descriptions of the combinations tested are included in table V.

The tests were run in the variable-density wind tunnel (reference 7) at a test Reynolds Number of approximately 3,100,000 (effective R = 8,200,000). In addition, values of the maximum lift were obtained at a test Reynolds Number of approximately 1,400,000 (effective R = 3,700,000). The testing procedure and test precision are about the same as for an airfoil (reference 7).

RESULTS

As in the preceding papers on the wing-fuselage interference investigation, the test results are given in tables I, II, III, IIIa, and V supplemented with figures 5 and 6 to illustrate the discussion. The characteristics are presented as standard nondimensional coefficients based on the original wing areas of 150 square inches and on the mean chords of 5 inches. The methods of analysis and of presentation of the results are explained in reference 1.

Tables I and II, taken from reference 1, contain the characteristics of the wing and the fuselage, respectively. Table III, continued from reference 5, presents for the different combinations the sums of the fuselage characteristics and interferences at various angles of attack. Table IIIa presents the sums of the characteristics and interferences of the tail surfaces. The characteristics of the combinations themselves can be determined by adding the corresponding items in tables I, III, and IIIa.

Table IV of reference 1, which presents data for disconnected combinations (combinations for which the forces on the components are measured separately), is discontinued herein because no data of this nature were obtained.

Table V, continued from reference 5, contains the principal geometric and aerodynamic characteristics of the combinations. The values d/c and k/c represent the longitudinal and vertical displacements, respectively, of the wing quarter-chord axis measured (in mean chord lengths) positive ahead of and above the quarter-length point of the fuselage axis. The value i_w is the angle of wing setting.

The last nine columns of table V present the following important aerodynamic characteristics:

a, lift-curve slope (in degree measure) as determined in the low lift coefficient range for an effective aspect ratio of 6.86. This value of the aspect ratio differs from the actual value for the models because the lift results are not otherwise corrected for tunnel-wall interference.

e, Oswald's airplane, or span, efficiency factor. (See reference 1.)

$C_{D_{e_{min}}}$, minimum effective profile-drag coefficient

$$\left(C_D - \frac{C_L^2}{\pi A}\right)_{min}.$$

$C_{L_{opt}}$, optimum lift coefficient, i.e., the lift coefficient corresponding to $C_{D_{e_{min}}}$.

n_o, aerodynamic-center position, indicating approximately the location of the aerodynamic center ahead of the wing quarter-chord axis as a fraction of the mean wing chord. Numerically,

$$n_o = \frac{dC_{m_{c/4}}}{dC_L} \text{ at zero lift.}$$

C_{m_o}, pitching moment at zero lift.

$C_{L_{ib}}$, lift coefficient at the interference burble, i.e., the value of lift coefficient beyond which the air flow has a tendency to break down as indicated by an abnormal drag increase.

$C_{L_{max}}$, maximum lift coefficient given for two different values of the effective Reynolds Number. (See reference 1.) The turbulence factor employed in this report to obtain the effective R from the test R is 2.64.

As in reference 2, the values of the effective Reynolds Number differ somewhat from those given in reference 1 because of a more accurate determination of the turbulence factor for the tunnel. The values of effective Reynolds Number given in reference 1 are subject to correction by a factor of 1.1.

DISCUSSION

A comparison of the aerodynamic characteristics of low-wing round-fuselage combinations for the unfilleted, filleted, and straight-side juncture conditions are presented in figure 5. The minimum drags of the three combinations are approximately the same, the variation being but little outside possible experimental error. The unfilleted round-fuselage combination exhibits a moderately early interference burble and a reduced value of the maximum lift coefficient. The drag and pitching-moment curves for the other two combinations are approximately the same, and the measured ratios of $C_{L_{max}}$ to $C_{D_{e_{min}}}$ were practically equal.

The pitching-moment characteristics of combinations, however, are not of much practical interest unless the effects of horizontal tail surfaces are included. From figure 6, it is immediately apparent that the pitching-moment (and the drag) curves for the low-wing round-fuselage combinations with tail surfaces both with straight-side junctures and tapered fillets are practically identical. The pitching-moment curve appears satisfactory as regards slope and shape, and the increments to the minimum and induced drags due to the horizontal tail surfaces are noticeably small. For purposes of design, the increases shown in the maximum lift cannot be considered real because the elevator flaps were undeflected.

Any further analysis of the effects of the horizontal tail surfaces and of their associated interferences is beyond the scope of this paper and will be covered in a future report on the interference between wing-fuselage and tail. Only the low-wing combinations have been discussed as they are the more interesting ones from considerations of interference at the wing roots. The high-wing combinations exhibited no unusual effects, the general conclusions drawn in preceding reports of the wing-fuselage interference investigation still apply, and their characteristics are given in table V.

CONCLUDING REMARKS

The modification of a round fuselage to provide straight-side junctures appeared very effective aerodynamically. The resulting low-wing combination possessed practically the same characteristics as the filleted condition. This comparison was unaffected by the addition of horizontal tail surfaces.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., February 7, 1938.

REFERENCES

1. Jacobs, Eastman N., and Ward, Kenneth E.: Interference of Wing and Fuselage from Tests of 209 Combinations in the N.A.C.A. Variable-Density Tunnel. T.R. No. 540, N.A.C.A., 1935.

2. Sherman, Albert: Interference of Wing and Fuselage from Tests of 28 Combinations in the N.A.C.A. Variable-Density Tunnel. T.R. No. 575, N.A.C.A., 1936.

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4. Sherman, Albert: Interference of Wing and Fuselage from Tests of 18 Combinations in the N.A.C.A. Variable-Density Tunnel. Combinations with Split Flaps. T.N. No. 640, N.A.C.A., 1938.

5. Sherman, Albert: Interference of Wing and Fuselage from Tests of 17 Combinations in the N.A.C.A. Variable-Density Tunnel. Combinations with Special Junctures. T.N. No. 641, N.A.C.A., 1938.

6. Hibbard, Hall L.: Speed Made Good is Lockheed's Slogan in Air and Shop - Model 14. Aviation, vol. 36, no. 7, July 1937, pp. 32-34, 75.

7. Jacobs, Eastman N., and Abbott, Ira H.: The N.A.C.A. Variable-Density Wind Tunnel. T.R. No. 416, N.A.C.A., 1932.

TABLE I - AIRFOIL CHARACTERISTICS

Taken from reference 1

Airfoil	C_L	C_{D_0}	$C_{m_{c/4}}$	C_L	C_{D_0}	$C_{m_{c/4}}$	C_L	C_{D_0}	$C_{m_{c/4}}$
	$\alpha = 0°$			$\alpha = 4°$			$\alpha = 12°$		
Tapered N.A.C.A. 0018-09	0.000	0.0093	0.000	0.305	0.0099	0.006	0.910	0.0146	0.013

TABLE II - FUSELAGE CHARACTERISTICS

Taken from reference 1

Fuselage	Engine	C_L	C_D	[1]C_{m_F}	C_L	C_D	[1]C_{m_F}	C_L	C_D	[1]C_{m_F}	C_L	C_D	[1]C_{m_F}	C_L	C_D	[1]C_{m_F}
		$\alpha = 0°$			$\alpha = 4°$			$\alpha = 8°$			$\alpha = 12°$			$\alpha = 16°$		
Round	None	.000	.0041	.000	.001	.0042	.016	.005	.0049	.028	.011	.0062	.035	.019	.0085	.038

[1]Pitching-moment coefficient about the quarter-chord point of the fuselage.

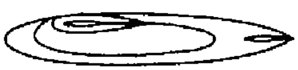
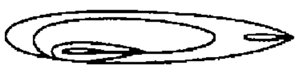
TABLE III - LIFT AND INTERFERENCE, DRAG AND INTERFERENCE, AND PITCHING MOMENT AND INTERFERENCE OF FUSELAGE IN WING-FUSELAGE COMBINATIONS

Combination	ΔC_L	ΔC_{D_e}	$\Delta C_{m_{c/4}}$	ΔC_L	ΔC_{D_e}	$\Delta C_{m_{c/4}}$	ΔC_L	ΔC_{D_e}	$\Delta C_{m_{c/4}}$
	$\alpha = 0^\circ$			$\alpha = 4^\circ$			$\alpha = 12^\circ$		
306	0.008	0.0029	-0.001	0.019	0.0033	0.003	0.044	0.0059	0.012
307	-.008	.0029	.001	.013	.0028	.005	.037	.0044	.011
308	-.017	.0025	.009	-.011	.0027	.017	-.004	.0052	.032
309	.017	.0025	-.009	.036	.0027	-.004	.046	.0047	.006

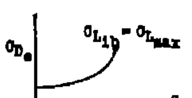
TABLE IIIa - LIFT AND INTERFERENCE, DRAG AND INTERFERENCE, AND PITCHING MOMENT AND INTERFERENCE OF TAIL SURFACES IN COMBINATIONS

Combination	ΔC_L	ΔC_{D_e}	$\Delta C_{m_{c/4}}$	ΔC_L	ΔC_{D_e}	$\Delta C_{m_{c/4}}$	ΔC_L	ΔC_{D_e}	$\Delta C_{m_{c/4}}$
	$\alpha = 0^\circ$			$\alpha = 4^\circ$			$\alpha = 12^\circ$		
310	0.005	0.0011	0.009	0.030	0.0012	-0.050	0.097	0.0025	-0.190
311	-.005	.0011	-.009	.022	.0015	-.062	.078	.0041	-.166
312	-.003	.0007	.020	.027	.0008	-.037	.083	.0015	-.172
313	.003	.0007	-.020	.027	.0014	-.073	.061	.0038	-.171

TABLE V. PRINCIPAL AERODYNAMIC CHARACTERISTICS OF COMBINATIONS

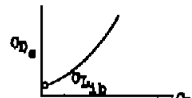
Diagrams representing combinations	Combination	Remarks	Longitudinal position d/c	Vertical position k/c	Angle of wing setting i_w (deg.)	Lift-curve slope (per degree) a, A = 6.86	Span efficiency factor e	$C_{D_{e_{min}}}$	$C_{L_{opt}}$	Aerodynamic center position n_0	C_{m_0}	Lift coefficient at interference burble [1]$C_{L_{ib}}$	[2]$C_{L_{max}}$ Effective R = 8.2 x 10⁶	[2]$C_{L_{max}}$ Effective R = 3.7 x 10⁶
Tapered N.A.C.A. 0018-09 airfoil with round fuselage														
		Wing alone	-	-	-	0.077	0.90	0.0095	0.00	0.020	0.000	[A]1.4	[c]1.48	[c]1.25
	306	With tapered fillets (Same as combination 331, reference 2, except for lacquered finish)	0.00	0.22	0	.080	.85	.0122	-.02	.053	-.001	[A]1.6	[c]1.65	[a]1.36
	307	With tapered fillets (Same as combination 334, reference 2, except for lacquered finish)	0	-.22	0	.081	[4].85	.0122	.02	.050	.001	[A]1.5	[c]1.57	[a]1.26
	308	With straight-side junctures	0	.22	0	.078	[5].85	.0118	-.03	.041	.010	[A]1.5	[b]1.58	[a]1.27
	309	- - do - - -	0	-.22	0	.079	[4].85	.0118	.05	.041	-.010	[A]1.5	[c]1.50	[a]1.23
	310	With straight-side junctures horizontal tail surfaces, $i_s = 0°$	0	.22	0	.086	[5].85	.0126	.02	-.127	.016	[A]1.7	[c]1.75	[a]1.48
	311	- - do - - -	0	-.22	0	.086	[5].85	.0128	-.02	-.123	-.016	[A]1.6	[c]1.66	[a]1.40
	312	With tapered fillets, horizontal tail surfaces, $i_s = 0°$	0	.22	0	.087	[5].85	.0129	.02	-.135	.019	[A]1.8	[c]1.84	[a]1.50
	313	- - do - - -	0	-.22	0	.087	[5].85	.0128	-.02	-.137	-.019	[A]1.7	[c]1.72	[a]1.37

[1]Letters refer to types of drag curves associated with the interference burble as follows:



Type A

Type B



Type C

[2]Letters refer to condition at maximum lift as follows:
[a]reasonably steady at $C_{L_{max}}$
[b]small loss of lift beyond $C_{L_{max}}$
[c]large loss of lift beyond $C_{L_{max}}$ and uncertain value of $C_{L_{max}}$

[4]Poor agreement over whole range

[5]Poor agreement in high-lift range

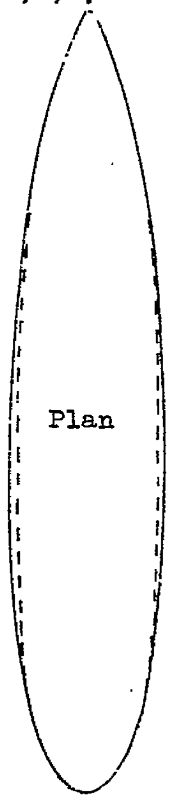
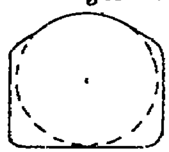


Figure 1. - The straight-side juncture modification.

x (in.)	y_1 (in.)	y_2 (in.)
0	1.403	-
1.0	1.381	-
2.0	1.308	1.598
3.0	1.177	1.439
4.0	.965	1.179
5.0	.588	.718
5.51	0	0

- - - - - - Round fuselage
——————— With straight-side juncture modification.



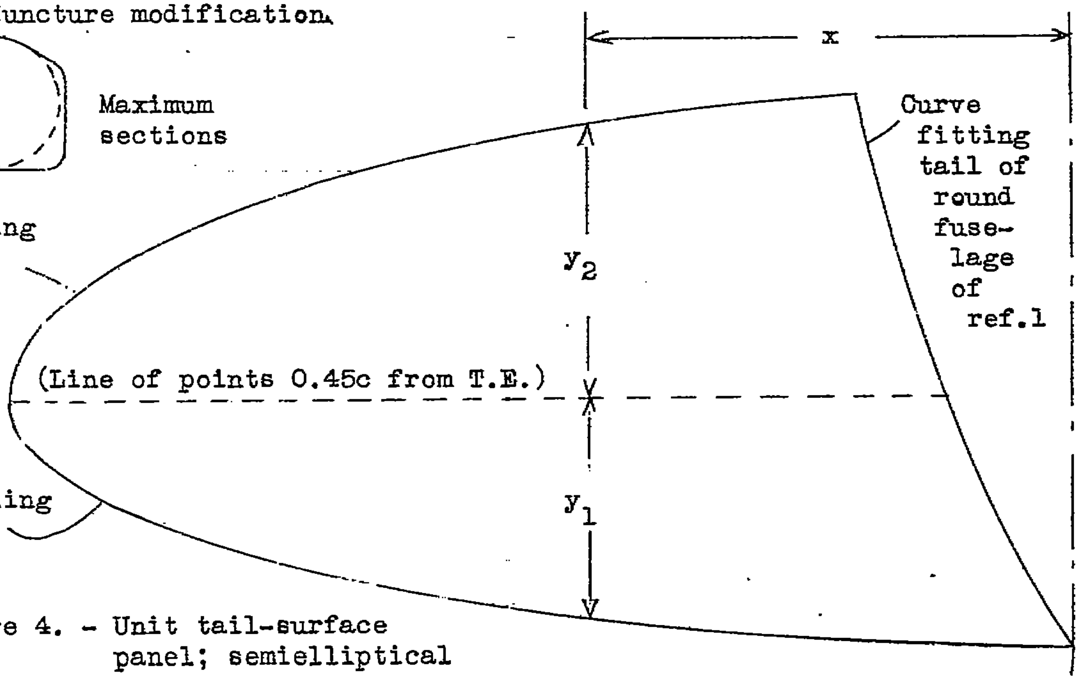


Figure 4. - Unit tail-surface panel; semielliptical plan form, N.A.C.A. 0009 sections.

Figure 2. - Combination 309 (Combination 308 inverted) showing cross-section shape of straight-side junctures.

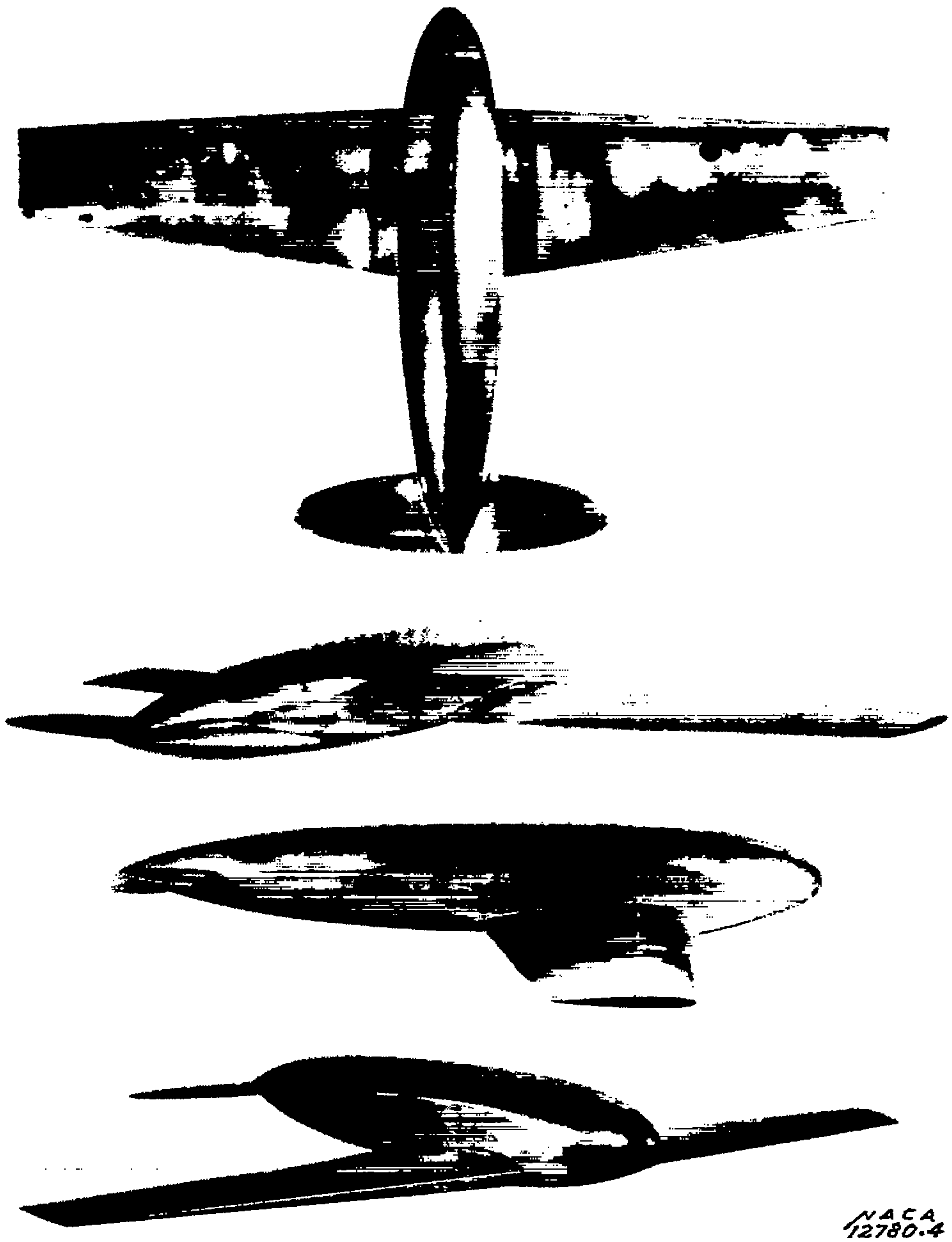


Figure 3. - Combination 311 (Combination 310 inverted) showing straight-side junctures and horizontal tail surfaces

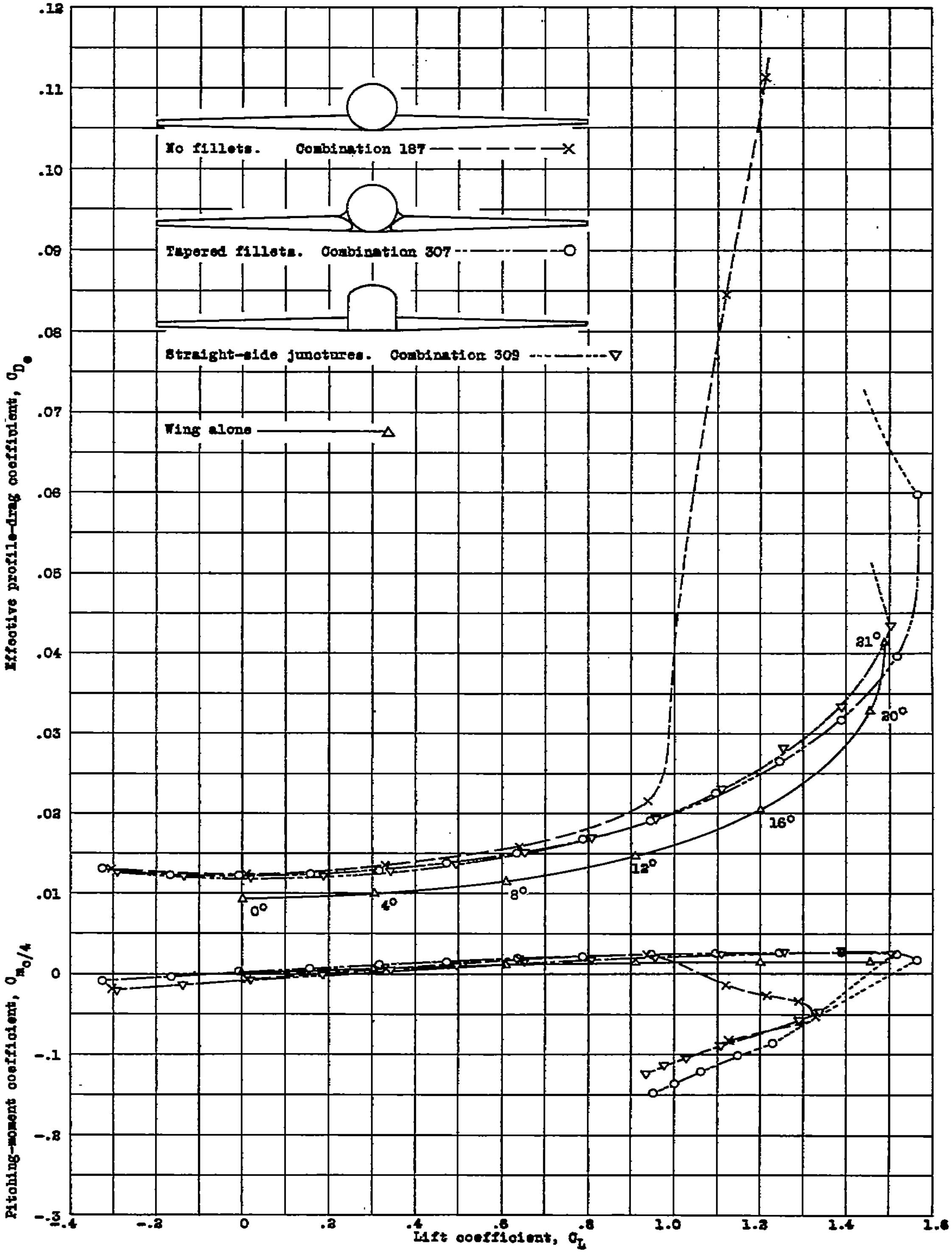


Figure 5. - Effect of straight-side junctures on the low-wing combination; round fuselage, tapered N.A.C.A. 0018-09 airfoil; $k/c = -0.22$

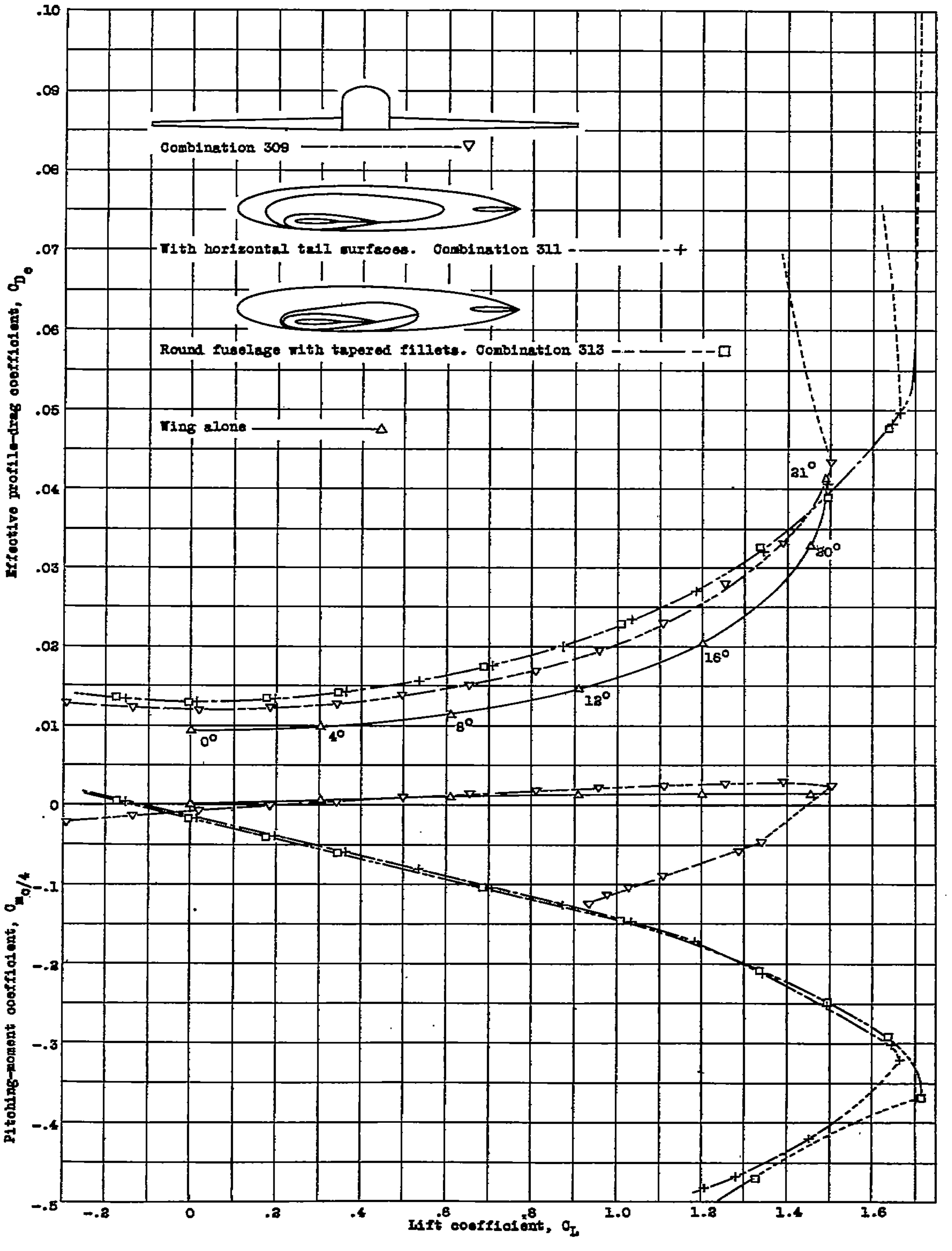


Figure 6. – Characteristics for low-wing combination with straight-side junctures and horizontal tail surfaces; round fuselage, tapered N.A.C.A. 0018-09 airfoil; $\bar{x}/c = -0.22$, $i_s = 0°$.